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6   UNITED STATES PATENT APPLICATION
7   FOR
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9   ENCODING SYSTEM
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2   FIELD OF THE INVENTION

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4   The present invention relates generally to encoding systems and, for

5   example, to encoding systems and methods for determining position and po-

6   sition changes of a moving member and to printing devices with such encod-

7   ing systems.

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9   BACKGROUND OF THE INVENTION

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11   Encoding systems for sensing relative movements usually have a row of

12   equidistantly spaced encoder marks attached to a first member and a sensor

13   arrangement attached to a second member which is movable with relation to

14   the first one. When the encoding marks move past the sensor arrangement

15   signals according to the detected marks are generated. By counting the sig-

16   nals, information regarding the position change between the two members

17   (i.e. relative-position information) is obtained.

18   An example of such a system is a wheel with radial encoder marks

19   mounted on a rotating axle, for example a pulley axle of a belt arrangement in

20   an ink-jet printer. Each time a mark passes an (e.g. optical or magnetic) sen-

21   sor, a signal is generated which indicates that the wheel has turned by one

22   mark. Another example is a belt of an ink-jet printer equipped with a linear

23   row of encoder marks. Each encoder signal indicates a belt advance of one

24   mark. However, if all marks are identical, no absolute-position information is

25   provided by such an encoder system.

26   In order to provide absolute-position information, it is known to equip an

27   encoder with at least one index mark (or "reference mark"). Two types are

28   known:

29   In double-channel (or multi-channel) encoders, the encoding marks and

30   the reference mark are separately arranged and viewed by individual sensors

31   (for example, US patent no. 5,206,645, Fig. 3).

32   In single-channel encoders, the different marks are arranged in one sin-

33   gle encoder scale. Examples of such single-channel encoders are, for exam-

1   ple, described in US patents nos. 4,786,803, 4,789,874, 5,206,645 and

2   5,411,340. In these single-channel encoders, the index mark is wider than the

3   encoder marks, and in some of them one or more of the encoder marks are

4   "hidden" by the index mark. The sensor generates different signals for the

5   marks of different widths, which enables the two types of marks to be distin-

6   guished. According to US patent no. 5,411,340, the virtual position of the hid-

7   den encoder mark is estimated.

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9   SUMMARY OF THE INVENTION

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11   A first aspect of the invention is directed to an encoding system for de-

12   termining position and position changes of a moving member. According to

13   the first aspect, the encoding system comprises a sequence of encoder

14   marks forming incremental patterns and at least one index pattern, wherein

15   two subsequent incremental patterns are indicative of an incremental-

16   position-change of the moving member and the index pattern is indicative of a

17   reference position of the moving member. The system further comprises a

18   sensor arrangement viewing a section of the encoder-mark sequence, the

19   length of which is greater than one position-change increment and an ana-

20   lyzer arranged to analyze an encoder-mark pattern in the viewed section with

21   regard to the incremental patterns and the index pattern and to generate, in

22   response to a pattern match found, at least one of an incremental-position-

23   change signal and an index signal.

24   According to another aspect, an encoding system is provided for deter-

25   mining position and position changes of a moving member. The encoding

26   system comprises a row of encoder marks arranged along the moving mem-

27   ber in a generally regular manner to provide incremental-position-change in-

28   formation. The system further comprises at least one index marking in the

29   form of a predefined pattern of encoder marks which represents a distur-

30   bance of the regular encoder-mark arrangement and a sensor arrangement

31   viewing a section of the row of encoder marks and arranged to provide a

32   viewed pattern of the encoder-mark section. The system further comprises an

33   analyzer arranged to analyze the viewed pattern to generate incremental-

1   position-change signals on the basis of the encoder marks and an index sig-
2   nal in response to a detection of the predefined index mark pattern. The in-
3   cremental-position-change signals are also able to be generated also in that
4   section of the encoder-mark row in which the regular encoder-mark arrange-
5   ment is disturbed by the index marking.

6   According to another aspect, an encoding system is provided for deter-
7   mining position and position changes of a moving member. The encoding
8   system comprises a row of identical encoder marks forming incremental pat-
9   terns and at least one index pattern, wherein two subsequent incremental
10   patterns are indicative of an incremental position-change of the moving mem-
11   ber and the index pattern is indicative of a reference position of the moving
12   member. The system further comprises a sensor arrangement detecting a
13   pattern of a section of the encoder-mark row and an analyzer arranged to
14   analyze the detected encoder-mark pattern with regard to the incremental
15   patterns and the index pattern and to generate, in response to an incre-
16   mental-pattern match found, an incremental-position-change signal and, in
17   response to an index-pattern match found, an index signal.

18   According to another aspect, a printing device is provided having an en-
19   coding system for determining position and position changes of a moving re-
20   cording medium conveyor to determine the position of a recording medium
21   placed on the conveyor. The encoding system comprises a sequence of en-
22   coder marks forming incremental patterns and at least one index pattern,
23   wherein two subsequent incremental patterns are indicative of an incremental
24   position-change of the moving member and the index pattern is indicative of a
25   reference position of the moving member. The system further comprises a
26   sensor arrangement viewing a section of the encoder-mark sequence, the
27   length of which is greater than one position-change increment and an ana-
28   lyzer arranged to analyze an encoder-mark pattern in the viewed section with
29   regard to the incremental patterns and the index pattern and to generate, in
30   response to a pattern match found, at least one of an incremental-position-
31   change signal and an index signal.

32   According to another aspect, a printing device is provided having an en-
33   coding system for determining position and position changes of a moving

1   member to determine the position of a recording medium placed on the con-

2   veyor. The encoding system comprises a row of encoder marks arranged

3   along the moving member in a generally regular manner to provide incre-

4   mental-position-change information. The system further comprises at least

5   one index marking in the form of a predefined pattern of encoder marks which

6   represents a disturbance of the regular encoder-mark arrangement and a

7   sensor arrangement viewing a section of the row of encoder marks and ar-

8   ranged to provide a viewed pattern of the encoder-mark section. The system

9   further comprises an analyzer arranged to analyze the viewed pattern to gen-

10   erate incremental-position-change signals on the basis of the encoder marks

11   and an index signal in response to a detection of the predefined index mark

12   pattern. The incremental-position-change signals are enabled to be generated

13   also in that section of the encoder-mark row in which the regular encoder-

14   mark arrangement is disturbed by the index marking.

15   According to another aspect, a printing device is provided having an en-

16   coding system for determining position and position changes of a moving

17   member to determine the position of a recording medium placed on the con-

18   veyor. The encoding system comprises a row of identical encoder marks

19   forming incremental patterns and at least one index pattern, wherein two sub-

20   sequent incremental patterns are indicative of an incremental position-change

21   of the moving member and the index pattern is indicative of a reference posi-

22   tion of the moving member. The system further comprises a sensor arrange-

23   ment detecting a pattern of a section of the encoder-mark row and an ana-

24   lyzer arranged to analyze the detected encoder-mark pattern with regard to

25   the incremental patterns and the index pattern and to generate, in response

26   to an incremental-pattern match found, an incremental-position-change signal

27   and, in response to an index-pattern match found, an index signal.

28   According to another aspect, a method is provided of determining posi-

29   tion and position changes of a moving member using a sequence of encoder

30   marks which forms incremental patterns and at least one index pattern,

31   wherein two subsequent incremental patterns are indicative of an incremental

32   position-change of the moving member and the index pattern is indicative of a

33   reference position of the moving member, comprising the steps: viewing a

1   section of the encoder-mark sequence, the length of which is greater than

2   one position-change increment; analyzing an encoder-mark pattern in the

3   viewed section with regard to the incremental patterns and the index pattern;

4   and generating, in response to a pattern match found, at least one of an in-

5   cremental-position-change signal and an index signal.

6   According to another aspect, a method is provided of determining posi-

7   tion and position changes of a moving member using a row of encoder marks

8   arranged along the moving member in a generally regular manner to provide

9   incremental-position-change information; at least one index marking in the

10   form of a predefined pattern of encoder marks which represents a distur-

11   bance of the regular encoder-mark arrangement, comprising the steps: view-

12   ing a section of the row of encoder marks; providing a viewed pattern of the

13   encoder-mark section; analyzing the viewed pattern to generate incremental-

14   position-change signals on the basis of the encoder marks and an index sig-

15   nal in response to a detection of the predefined index mark pattern. The in-

16   cremental-position-change signals are enabled to be generated also in that

17   section of the encoder-mark row in which the regular encoder-mark arrange-

18   ment is disturbed by the index marking.

19   Other features are inherent in the methods and products disclosed or

20   will become apparent to those skilled in the art from the following detailed de-

21   scription of embodiments and its accompanying drawings.

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23   DESCRIPTION OF THE DRAWINGS

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25   Embodiments of the invention will now be described, by way of example,

26   and with reference to the accompanying drawings, in which:

27   Fig. 1   illustrates a linear-encoding system;

28   Fig. 2   illustrates an angular encoding system;

29   Fig. 3   schematically shows a sensor arrangement;

30   Fig. 4   illustrates an exemplary index marking, a regular arrangement

31   of encoding marks, and a regular arrangement disturbed by the index mark-

32   ing;

33   Fig. 5   shows different possible viewed patterns, when the index

1   marking of Fig. 4 is used, and illustrates one embodiment of a pattern ana-

2   lyzer arranged to generate incremental and index signals in dependence on

3   the viewed pattern;

4   Fig. 6   shows a flow diagram of another embodiment of a pattern

5   analyzer;

6   Fig. 7   illustrates a movement of an encoder mark with the index

7   marking of Fig. 4 and 5 past a sensor arrangement;

8   Fig. 8   shows different viewed pattern and illustrates signal genera-

9   tion similar to Fig. 5, but for another exemplary index marking;

10   Fig. 9   illustrates a printing device equipped with a linear-encoding

11   system of Figs. 1, 2 to 8.

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13   DESCRIPTION OF THE PREFERRED EMBODIMENTS

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15   Figs. 1 and 2 illustrate linear and angular encoding systems. Before pro-

16   ceeding further with the detailed description of Figs. 1 and 2, however, a few

17   items of the embodiments will be discussed.

18   In the embodiments, the encoding system has encoder marks arranged

19   in a sequence (or row) which are fixed to a moving member or a complemen-

20   tary non-moving member. The encoder marks used in a particular embodi-

21   ment are equal, and they are regularly (equidistantly) arranged (except for an

22   index marking region, as will be explained below). A sensor arrangement

23   views the encoder-mark row. Each time an encoder mark passes a sensor of

24   the sensor arrangement, a signal is generated. At least in the region outside

25   the index marking each signal of a particular sensor represents an advance of

26   the moving member by one encoding mark distance. Accordingly, incremental

27   counting of these signals, in principle, enables position changes of the moving

28   member (or its "relative position") to be determined; the position change cor-

29   responds to the encoding mark distance times the number of counted signals

30   (actually, in the embodiments, the incremental position-change-signals are

31   not simply based on individual sensor signals, but rather on certain combina-

32   tions (or patterns) of signals from the different sensors of the sensor ar-

33   rangement, as will be explained below).

1   In order to obtain an absolute position indication, an index (or reference)
2   marking is also provided. It is indicative of a particular reference point on the
3   (generally longitudinally extended) moving member, called "reference posi-
4   tion". By starting the incremental counting at the index marking, i.e. by com-
5   bining the absolute reference-position information of the index marking and
6   the relative position information of the accumulated position-change signals,
7   any position of the moving member can be absolutely determined.

8   In some of the preferred embodiments the encoding system has only
9   one index marking to provide unambiguous absolute position information. If,
10   however, index marking ambiguities can be resolved, two or more index
11   markings may be provided; (for example, in a printer with several print sta-
12   tions equipped with sensors responsive to index markings, the ambiguity be-
13   tween a plurality of index markings can be effectively resolved if the distance
14   between index markings is larger than the distance between the print sta-
15   tions).

16   In the preferred embodiments, the index marking is not arranged in a
17   separate channel and has no mark with a shape different from the encoder
18   marks. Rather, the index marking is a predefined pattern formed by equal en-
19   coder marks which can be considered as a disturbance of the regular en-
20   coder-mark arrangement. Consequently, the encoder-mark arrangement is
21   strictly regular only in those regions of the encoder-mark row which are not
22   disturbed by the index pattern; the entire arrangement (including the index
23   marking) is called "generally regular".

24   The embodiments described enable relative position information (based
25   on incremental signals) and absolute position information (based on index
26   signals) to be obtained with a smaller relative error than in conventional sys-
27   tems which used different sensors or encoder marks of different shape or size
28   to distinguish between incremental and index markings. In the embodiments,
29   identical markings and one and the same sensor arrangement is used to de-
30   tect both incremental and index markings which helps reduce possible sys-
31   tematic shifts between the relative and absolute position determination. Unlike
32   systems with separate sensors for encoding and index marks, the relative
33   error between the detected encoding marks and the index marking is zero or

1   negligible, and practically no systematic or random errors are present, in the

2   embodiments. Accordingly, when the embodiments of the encoding system,

3   for example, are used in printers, the image registration between different

4   print stations and, consequently, the achievable image quality, may be im-

5   proved.

6   The sensor arrangement views a section of the encoder-mark row. It is

7   arranged to provide information representative of the pattern of the viewed

8   encoder-mark section also called the viewed or detected pattern).

9   In the preferred embodiments, the sensor arrangement has a plurality of

10   sensor elements which simultaneously view a plurality of fields of the en-

11   coder-mark row, and, accordingly, can simultaneously detect a plurality of

12   encoder marks in the viewed encoder-mark section.

13   In other embodiments the sensor arrangement has a sensor which suc-

14   cessively detects individual encoder marks (or sub-sections) of the encoder-

15   mark section upon a movement of the moving member. The encoding system

16   combines the successively detected encoder marks to form a representation

17   of the encoder-mark pattern in the section. Embodiments with successive de-

18   tection of encoder marks are less preferred since the complete encoder-mark

19   pattern is only obtained with a delay since a full pattern is only known when

20   the last encoder mark of the section has been detected.

21   The length of the index pattern is chosen such that the encoder-mark

22   pattern and the index pattern can be distinguished (i.e. the two patterns are

23   orthogonal or quasi-orthogonal, even in the presence of noise (e.g. errone-

24   ously detected or not detected marks)). In some of the embodiments, the

25   length of the viewed encoder-mark section corresponds to the length of the

26   index marking. However, if a unique identification of the index marking, even

27   in the presence of noise, is already enabled by a part of the index marking, it

28   may be sufficient to view only an encoder-mark section shorter than the

29   length of the index marking. Conversely, to improve robustness against noise,

30   in some embodiments the length of the viewed encoder-mark section is larger

31   than the length of the index marking.

32   An analyzer receives the pattern information detected by the sensor ar-

33   rangement. The analyzer is, for example, a digital processor which compares

1   viewed patterns with stored predetermined patterns and finds matches be-

2   tween them. The analyzer may be a device especially dedicated to the pat-

3   tern analysis. Alternatively, it may be part of another device, e.g. a controller

4   of an apparatus (e.g. a printer) with which the encoding system is associated.

5   For example, the analyzer may then be a process executed in the controller

6   besides other processes. The analyzer generates encoder signals which indi-

7   cate the incremental position-changes of the moving member on the basis of

8   the encoder marks. Furthermore, it generates an index signal in response to a

9   detection of the predefined index mark pattern.

10   In the embodiments, the sensor arrangement detects a multiplicity of

11   encoder marks in the viewed section, although, in principle, one encoder

12   mark would be sufficient to generate an encoder signal providing incremental

13   position-change information. In other words, the detected multiplicity of en-

14   coder marks carry redundant incremental position-change information at least

15   in regions of regular encoder-mark arrangement (i.e. in regions in which the

16   regular encoder-mark arrangement is not disturbed by the index marking).

17   The disturbed region includes additional information, e.g. the index marking.

18   Although this reduces or even takes away the redundancy of the incremental

19   position-change information, sufficient incremental-position-change informa-

20   tion is still included to enable incremental position-change signals to be gen-

21   erated even in that part of the encoder-mark arrangement which is disturbed

22   by the index marking.

23   Considering the index marking as a disturbance of a regular encoder-

24   mark arrangement (as above) is one possible way to describe the encoding

25   system of the embodiments. Another possible description treats the genera-

26   tion of the incremental-position-change signals and the generation of the in-

27   dex signal in an equal manner. In this alternative description, the encoder-

28   mark row is considered to form incremental patterns and at least one index

29   pattern. Two subsequent incremental patterns are indicative of an incremental

30   position-change of the moving member. The index pattern is indicative of the

31   moving member's absolute reference position. By definition, the incremental

32   patterns and the index pattern may be considered to have equal lengths. In

33   the embodiments, one unit of incremental position-change is smaller than the

1   length of the incremental pattern, which means that subsequent incremental

2   patterns overlap. The section of the encoder-mark row viewed by the sensor

3   arrangement is greater than one such position-change increment. Preferably,

4   the length of the viewed encoder-mark section is equal to the length of the

5   incremental patterns and the index pattern, but it may also be greater or

6   smaller than that. The analyzer "knows" all predefined patterns (i.e. the in-

7   cremental patterns and the index pattern) and generates, in response to an

8   incremental-pattern match found, an incremental-position-change signal, and,

9   in response to an index-pattern match found, an index signal.

10 In the embodiments, the encoder marks are identical. For example, if

11 the encoding system is an optical system, the encoder marks have the same

12 shape, size and color and the same orientation on the moving member. Ac-

13 cordingly, the index mark is not defined by special marks, but by a special

14 pattern of the identical encoder marks.

15 In some of the embodiments, the encoding system is an angular system

16 in which the encoder marks are arranged in a circular row on a rotating mem-

17 ber. In other embodiments the encoding system is linear; the encoder marks

18 are arranged in a linear row parallel to the moving member's advance direc-

19 tion; their orientation is typically perpendicular to the advance direction (but

20 the marks may be inclined to the advance direction if lateral displacements of

21 the moving member are also to be detected). Of course, the term "moving

22 member" does not imply that the member is necessarily rigid. Rather, the

23 member may be flexible, such as, for example, a conveying belt in a printer or

24 a print medium (e.g. paper) on which the encoder marks are printed.

25 The described encoding system may, for example, be used in devices in

26 which a moving member has to be accurately positioned (such as in robots)

27 or the position of a moving member has to be accurately known (such as in

28 printing scanning measurement devices). For example, in an embodiment of

29 a printing device described below, the encoding system is used for determin-

30 ing position (i.e. the absolute reference position) and position changes (i.e.

31 the relative position) of a recording medium conveyor, which is, for example,

32 a belt or drum conveyor. Preferably, the encoding system when used in a

33 printing device will determine the position of a recording medium placed on

1   and moved by the conveyor. By measuring the recording medium's position

2   relative to the conveyor by means of an additional sensor (e.g. a media pres-

3   ence sensor) and assuming that the recording medium does not move rela-

4   tive to the conveyor, a precise measurement of the conveyor's position and

5   position changes is an indirect precise measurement of the recording me-

6   dium's position and position changes. The sensor for example can be either

7   placed in fixed position to sense the entire width of the medium in one read-

8   ing or parked in a side position to sense the entire width of the medium in a

9   scanning movement, by means of a motor, in a direction perpendicular to the

10   medium advance direction. The row of encoder marks is arranged along the

11   conveyor. The printing device is a multicolor printer with a plurality of page-

12   wide print stations which extend over the recording medium conveyor and are

13   spaced from one another in the advance direction. Each print station is indi-

14   vidually equipped with a sensor arrangement, and an analyzer of the kind de-

15   scribed above is associated with each print station. The sensor arrangements

16   view the same row of encoder marks, but, due to the spaced arrangement of

17   the print stations, different sections of the encoder-mark row which are adja-

18   cent to the respective print station. Such a print-station-individual measure-

19   ment of the conveyor's relative and absolute position enables a precise regis-

20   tration of the images printed by the spaced print stations onto each other,

21   which improves the image quality. The improvement achieved by such a print-

22   station-individual measurement is particularly advantageous with non-rigid

23   conveyors, such as belt conveyors. For example, a belt may carry out oscilla-

24   tory movements with a component in a direction perpendicular to the re-

25   cording-medium-advance direction, and it may expand and shrink in the ad-

26   vance direction (e.g. due to temperature changes), which could generally in-

27   troduce registration errors between the print stations. The described print-

28   station-individual measurement limits the amount of registration errors intro-

29   duced between the print stations.

30   For certain applications, two orthogonal encoding systems of the kind

31   described may be used. For example, in order to enable the absolute position

32   of a movable tool on a two-dimensional surface (e.g. a table) to be deter-

33   mined, two orthogonal edges of the table may be equipped with rows of en-

1   coding marks, each including an index marking, as described herein.

2   Returning now to Figs. 1 and 2, encoding systems 1, 1' trace position

3   and position changes of a moving member 2, 2'. Fig. 1 illustrates a linear-

4   encoding system, and Fig. 2 an angular encoding system. The moving mem-

5   ber 2 of the linear system shown in Fig. 1 bears a linear row 3 composed of

6   individual encoder marks 4. The encoder marks 4 are in the shape of short

7   strokes or lines perpendicular to an advance direction of the moving member

8   2 (indicated by arrow 5). All encoder marks 4 are equal, and the distances

9   between them are also equal, except in a region of row 3 in which an index

10   marking is located (in the index marking, one or more encoding marks may be

11   missing or inserted between the normally spaced encoding marks). A section

12   6 of the row 3 of encoder marks 4 is viewed by a sensor arrangement 7. The

13   sensor arrangement 7 is mounted on a fixed structure, e.g. by a sensor sup-

14   port 8. In other embodiments, the encoder-mark row is fixed, whereas the

15   sensor arrangement is mounted on the moving member and is thus move-

16   able. Sensor output data is transferred to an analyzer 9 via a connection 10.

17   Functional components of the analyzer 9 are a sensor input component 11, a

18   comparator 12, a pattern memory 13, and a signal generator 14. The pattern

19   memory 13 stores representations of predefined patterns of encoder marks 4

20   as well as pattern attributes which indicate whether a stored pattern repre-

21   sents an incremental pattern or an index pattern. The sensor output data is

22   input via the input component 11. The comparator 12 compares the detected

23   pattern of encoder marks 4 with all stored patterns. If it finds a match between

24   the detected pattern and one of the stored patterns, it causes the signal gen-

25   erator 13 to generate an incremental-position-change signal 15 or an index

26   signal 16, if the attribute of the matching stored pattern indicates that it is an

27   incremental pattern or an index pattern.

28   In the angular encoder 1' of Fig. 2 the moving member is a rotating disk.

29   Correspondingly, the advance direction illustrated by arrow 5' is a section of a

30   circular line. The encoder marks 3' are arranged on the flat front of the rotat-

31   ing member 2', and are radially oriented. The sensor arrangement 7' is ar-

32   ranged to view the radially oriented encoder marks 3' on the face of the rotat-

33   ing member 2'. Regarding the analyzer 9, and the signals 15, 16 generated by

1   it, reference is made to the analyzer's description made above in connection

2   with Fig. 1.

3   Fig. 3 illustrates an embodiment of the sensor arrangement 7 arranged

4   to observe the section 6 of the row 3 of encoder marks 4. The sensor ar-

5   rangement 7 has a plurality of individual sensor elements 18, each of which

6   views a different field of row 3. The sensor elements 18, for example, are op-

7   tical sensors indicative of the presence or absence of an encoder mark 4

8   within the respective viewed field. The pitch of the sensor elements 18 corre-

9   sponds to the pitch of the encoder marks 4 (wherein in the regions of regular

10   encoder-mark arrangement each encoder mark is followed by a blank space;

11   accordingly, only every second sensor element 18 will see an encoder mark,

12   as explained in connection with Figs. 4 and 5 below). Furthermore, the size

13   and orientation of the sensor elements 18 correspond to the ones of the en-

14   coder marks 4. Accordingly, the sensor arrangement 7 is adapted to the en-

15   coder-mark row 3 to detect patterns of encoder marks 4. The encoder marks

16   4 will gradually move into and out of the encoder-mark area viewed by each

17   sensor element 18. A signal preprocessor 19 differentiates the sensor signals

18   and performs suitable signal processing in order to provide only one signal

19   when an encoder bar has moved into the respective viewed field and to de-

20   fine when this signal is triggered during this gradual movement (for example,

21   the signal is triggered when the encoding mark and the field are coincident).

22   Further, it combines the processed signals and forwards them to the analyzer

23   9 via line 10. In the example shown in Fig. 3, the sensor arrangement 7 has

24   ten sensor elements 18. The exemplary encoder-mark row 3 shown in Fig. 3

25   is shown in such a position in which an index marking disturbing the regular

26   arrangement of encoder marks 4 is viewed by the sensor arrangement 7, as

27   will be explained in connection with Fig. 4.

28   Fig. 4a illustrates an incremental-encoder-mark unit 20 composed of an

29   encoder mark 4 and a blank space 21. The encoder mark 4 and the blank

30   space 21 are represented by "1" and "0", respectively. Fig. 4c illustrates a

31   regular sequence of such units 20. This regular sequence is present in the

32   row 3 of encoder bars 4 outside the region which bears the index marking.

33   The period of this regular sequence (i.e. the distance between the center of

1   two consecutive encoder marks 4) corresponds to one incremental position-

2   change of the moving member. Incremental positions assigned to the incre-

3   mental encoder-mark units 20 are also shown in Fig. 4c (denoted by "22"). A

4   conventional encoder with a sensor which views and processes only single

5   encoder marks would provide an incremental-position-change signal each

6   time the center of an encoder mark (i.e. an incremental position 22 in Fig. 4c)

7   passes by the sensor.

8   Fig. 4b illustrates an exemplary index marking 23. It has a length of

9   eleven elements; it starts with three blank spaces 21, followed by five index

10 markings 4, and is terminated by three blank spaces 21. Although the index

11 marking 23 is a longitudinally extended object (longitudinally means "in the

12 advance direction"), the moving member's reference position 24, which is in-

13 dicated by the index marking, is, for example, at the center of the position of

14 the leftmost of the three blank spaces 21 in Fig. 4b.

15   Fig. 4d illustrates that the index marking 23 is "embedded" in the regular

16 arrangement of encoding marks 4 and blank spaces 21 of Fig. 4c. As can be

17 seen, the regular arrangement is disturbed by the index marking 23. In the

18 example of Fig. 4d, two encoding marks of the regular arrangement are re-

19 moved (thereby forming the two blank-space triples) and two blank spaces of

20 the regular arrangement are filled by encoder marks (thereby forming the five

21 adjacent encoder marks). Also indicated in Fig. 4d is the reference-position

22 24 of the index marking and incremental positions 22. The latter can be re-

23 constructed although two encoder marks 4 have been replaced by blank

24 spaces 21 and two blank spaces 21 by encoder marks 4, as will be explained

25 in connection with Fig. 5 below.

26   Incidentally, what is precisely considered as the "index marking" is a

27 matter of definition: for example, as can be seen in Fig. 4d, a possible differ-

28 ent definition might exclude the third blank space 21 at the right-hand side of

29 the index marking 23 in Fig. 4d.

30   In other embodiments, the index marking is only formed by missing en-

31 coder marks, but no additional marks are inserted between the regularly ar-

32 ranged encoder marks, as in Figs. 4b and 4d. In such embodiments, blank

33 spaces may not be used to describe the incremental patterns and the index

1 pattern, and sensor elements for viewing blank spaces in the regular ar-
2 rangement may not be provided.

3   Fig. 5 illustrates the pattern-analysis operation and signal generation
4 performed by the analyzer 9 (Figs. 1 and 2). On the left-hand side of Fig. 5, all
5 possible patterns are listed which may occur in the viewed section when the
6 encoder-mark row of Figs. 4c and 4d with the exemplary index marking 23 is
7 moved past the sensor arrangement. There are, in total, twenty-one different
8 possible patterns. The right-hand side of Fig. 5 is a Boolean operation table
9 which maps the possible twenty-one patterns to a certain incremental and
10 index signal output (wherein "0" indicates "no signal", and "1" indicates a
11 "signal"). The patterns P1 and P2 are the regular patterns which appear when
12 the regular part of the encoder-mark row is shifted past the sensor arrange-
13 ment. If the first viewed field (i.e. the rightmost in Fig. 5) is an index mark, an
14 incremental signal is generated, but if it is a blank space, no incremental sig-
15 nal is generated. The other patterns, P3 to P21 are irregular patterns which
16 are detected by the sensor arrangement when the index marking of Fig. 4b is
17 moved, field by field, into, and out of, the section viewed by the sensor ar-
18 rangement. An incremental signal is generated every second pattern. When
19 the index marking is completely within the viewed section (pattern P12), an
20 index signal is generated. A further movement of the index mark row causes
21 the index mark pattern to leave the viewed section (pattern P21), until the
22 regular pattern P2 is observed again. In all cases except P12 no index signal
23 is generated.

24   As can be seen in Fig. 5, the incremental-position-change information is
25 redundantly contained in the regular patterns P1 and P2. In order to obtain
26 the incremental-position-change information it would be sufficient to view only
27 one field of the encoder-mark row. However, the use of a sensor arrangement
28 viewing more fields enables the incremental signal to be generated even in
29 that region of the encoder-mark row which is disturbed by the index marking
30 (patterns P3 to P21). For example, if a sensor viewing only the first (right-
31 most) field were used, no incremental signal would erroneously be generated
32 for patterns P13 and P21 (although an incremental signal is due for these
33 patterns), and erroneous incremental signals would be generated for patterns

1   P16 and P18. Thus, viewing a pattern with a multiplicity of encoder marks and

2   analyzing the observed pattern as to whether it matches one of the prede-

3   fined incremental patterns, rather than viewing only one encoding mark, en-

4   ables the incremental-position-change information to be reconstructed even

5   from that region in which the regular arrangement is disturbed by the index

6   marking. Incidentally, it is clear from Fig. 5 that the incremental patterns over-

7   lap since the pattern length is eleven fields, whereas the distance between

8   incremental positions 24 (Fig. 4) only corresponds to two fields.

9   The pattern processing and signal generation illustrated in Fig. 5 is, for

10   example, implemented in the analyzer as follows: the 20 different possible

11   patterns P1 to P21 are stored in the pattern memory 13 (Fig. 1) together with

12   the attributes indicating whether an incremental signal and/or an index signal

13   is to be generated for the respective pattern. The comparator 12 (Fig. 2)

14   compares a detected pattern with all stored patterns and tries to find that

15   stored pattern which matches the detected pattern. Depending on the signal

16   attribute of the matching pattern found, the signal generator 14 (Fig. 1) gen-

17   erates no signal, an incremental signal or an index signal (or both of them,

18   see Fig. 8 below).

19   Fig. 5 illustrates an ideal case without pattern errors or detection errors.

20   In practice, however, pattern and detection errors may occur, for example, if

21   the row of encoder marks is contaminated by ink, or if a mark is erroneously

22   detected due to noise. Then, other ("incorrect") patterns than ones shown in

23   Fig. 5 may also be output by the sensor arrangement. In order to cope with

24   such erroneous detections, that pattern of the set of "correct" patterns shown

25   in Fig. 5 is assigned to a detected "incorrect" pattern which is closest to the

26   detected pattern. In some embodiments, the closest "correct" pattern is found

27   by a maximum likelihood estimation.

28   Fig. 6 shows a flow diagram of another embodiment of a pattern ana-

29   lyzer, based on calculating correlations between patterns. In block B1, a

30   viewed pattern is received at the pattern analyzer. In block B2', the viewed

31   pattern is correlated with the encoder pattern, which is "10101010101" in this

32   example. "Correlating" means counting the number of same digits; therefore

33   the correlation may go from 0 to 11. In block B2", the viewed pattern is corre-

1 lated with the index pattern, which is "00011111000" in this example. In block

2 B3' it is ascertained whether the correlation of the viewed pattern with the en-

3 coder pattern is higher than a certain threshold ("5" in the example of Fig. 6).

4 If the outcome is positive an incremental signal is generated, if, however, it is

5 negative, no incremental signal is generated (block B4'). In block B3" it is as-

6 certained whether the correlation of the viewed pattern with the index pattern

7 is higher than a certain other threshold ("9" in the example of Fig. 6). If the

8 outcome is positive an index signal is generated, if, however, it is negative, no

9 index signal is generated (block B4"). By appropriately choosing the thresh-

10 olds, robustness against noise may be optimized . For example, if the index-

11 pattern correlation threshold is set to 10, only correct readings of the index

12 pattern cause the generation of an index signal. If it is set to a value smaller

13 than 9, a wrong index signal generation may occur if one "1" of the index pat-

14 tern is read as a "0". The robustness against noise may be increased by view-

15 ing a longer section of the row of encoder marks (for example 13 encoder

16 marks, instead of the 11 marks shown in Fig. 6). The encoder-pattern correla-

17 tion threshold is generally set to a smaller value, as illustrated in Fig. 6, since

18 for a symmetric noise distribution, half of the length of the viewed encoder

19 pattern is the optimal threshold. In case the noise distribution is not symmetri-

20 cal, the optimal threshold would be higher or lower.

21   Fig. 7 illustrates how the encoder-mark row 3 of Fig. 4d is moved

22 through the "window" of the sensor arrangement. Four different "snapshots"

23 are shown, the viewed sections 6 of which correspond to patterns P1, P2, P5

24 and P12 of Fig. 5. As defined by the Boolean operation table of Fig. 5, incre-

25 mental signals 15 are generated when the patterns P1 and P5 are moved into

26 the sensor arrangement's window, and an index signal is generated when the

27 pattern P12 is moved into it.

28   Fig. 8 illustrates a pattern analysis and signal generation analogous to

29 Fig. 5, but for another example of an index marking denoted by 23'. The index

30 marking 23' has a length of six elements, it is composed of three encoder

31 marks 4, followed by three blank spaces 21. Eleven different patterns, de-

32 noted by R1 to R11 in Fig. 8, can be observed when a regular arrangement

33 (as shown in Fig. 4c) is overlaid with the index marking 23', and when such an

1   encoder-mark row is moved past the detector arrangement (which, in this ex-

2   ample, views only six elements). The pattern processing and signal genera-

3   tion corresponds to what has been described in connection with Fig. 5, which

4   illustrates that it is independent of the particular pattern chosen for the index

5   marking. Incidentally, one difference due to the different pattern chosen can

6   be seen in pattern R7: both the incremental signal and the index signal are

7   generated for pattern R7, whereas only the index signal, but no incremental

8   signal is generated for the corresponding pattern P12 of Fig. 5.

9   Fig. 9 illustrates a printing device 30 equipped with the linear-encoding

10   system 1 of Figs. 1, 3 to 7. The printing device 30 is a multicolor printer with

11   separate print bars 31 for the different colors to be printed (for example, cyan,

12   magenta, yellow and black). The print bars 31 extend over the full width of a

13   print medium 32, for example paper sheets (an already printed multicolor im-

14   age is shown at 33 in Fig. 9). The exemplary printer of Fig. 9 is an ink-jet

15   printer; other embodiments use other printing technologies, such as laser

16   printing, dye sublimation printing, thermal way printing, solid ink printing, etc.

17   The multicolor image to be printed is virtually separated into single-color

18   images to be printed by the respective single-color print bars 31 (some em-

19   bodiments have redundant print bars, for example, two print bars for each

20   color; in these embodiments, the single-color image to be printed is subdi-

21   vided between the print bars of the same color, for example, by use of appro-

22   priate print masks; other embodiments even have multicolor print bars). In

23   order to achieve high image quality, the individual single-color images are

24   printed onto the recording medium 32 onto each other in an aligned manner,

25   which is also called "registering" the images. Since the print bars 31 are

26   spaced in the recording-medium-advance direction 5, the different single-

27   color images are printed one after the other, and the downstream print bars

28   need to "know" where the first print bar printed its image onto the recording

29   medium 32 in order to achieve precise image registration. This is accom-

30   plished by the encoding system described above.

31   The printing device 30 has a moving member 2 in the form of a convey-

32   ing belt guided by rollers 34, at least one of which is driven (in other embodi-

33   ments, the moving member is a rotating drum). The row 3 of encoder marks 4

1   is arranged at one edge of the belt and parallel to it. The encoder marks 4

2   are, for example, printed onto the belt or a strip attached to the belt (or the

3   drum). The encoder marks 4 are oriented perpendicular to the advance direc-

4   tion 5 and are regularly arranged. An index marking 23 forms a disturbance of

5   their regular arrangement, as described above. Each print bar 31 is equipped

6   with an individual sensor arrangement 7 which views a section of the en-

7   coder-mark row 3 to provide print-bar-individual information about the relative

8   and absolute belt position. This information is used to individually register the

9   images printed by the print bars 31. A controller 35 controls the print activity

10   of individual dot-forming elements (e.g. ink nozzles in an ink-jet printer) of the

11   print bars 31 to print the required image. The controller 35 controls the print

12   activity such that each of the print bars 31 downstream of the first print bar 31

13   prints its image in a registered manner onto the first print bar's image. An

14   analyzer 9 of the kind described above is provided for each print bar 31. The

15   analyzers 9 are components of the controller 35; they are, for example, im-

16   plemented as analyzer processes executed by the controller 35 simultane-

17   ously with other processes (e.g. the process controlling the nozzle activity).

18   The signals representing encoder marks detected by the sensor arrange-

19   ments 7 are input to the controller 35, and the analyzers 9 generate the in-

20   cremental and index signals for each print bar 31 based on these sensor sig-

21   nals, as described above. In other embodiments, the print bars 31 are

22   equipped with individual analyzer devices or a common analyzer device dedi-

23   cated to process the detected encoder-mark patterns and generate the print-

24   bar-individual incremental and index signals which are supplied to the control-

25   ler 35.

26   The index and incremental signals are, for example, used to register the

27   print bar's images in the following way: an incremental counter is assigned to

28   each print bar. When the index marking 23 moves past a print bar 31 and is

29   detected by the print bar's sensor arrangement 7 so that an index signal is

30   generated for this print bar, the print bar's incremental counter is set to a ref-

31   erence value (for example to "0"). Each incremental signal due to a subse-

32   quent detection of an incremental pattern at this print bar causes the print

33   bar's incremental counter to be incremented. Accordingly, the current content

1   of each of the counters represents the current position of the belt (and, con-

2   sequently, of the recording medium 32 on the belt; it is assumed that the re-

3   cording medium does not move relative to the belt which is a reasonable as-

4   sumption in many applications) relative to a common reference point (i.e. the

5   reference position of the index marking 23). When the first print bar 31 starts

6   printing its image onto the recording medium 32 at a certain count of its asso-

7   ciated incremental counter, the controller 35 controls the print action of the

8   subsequent print bars 31 such that they also start to print their respective im-

9   age when the same count is reached in their respective incremental counter.

10   In this way, registration of the different images to be printed is accomplished.

11   The embodiments described enable relative position information (based

12   on incremental signals) and absolute position information (based on index

13   signals) to be obtained with a smaller relative error than in conventional sys-

14   tems which used different sensors or encoder marks of different shape or size

15   to distinguish between incremental and index markings.

16   All publications and existing systems mentioned in this specification are

17   herein incorporated by reference.

18   Although certain methods and products constructed in accordance with

19   the teachings of the invention have been described herein, the scope of cov-

20   erage of this patent is not limited thereto. On the contrary, this patent covers

21   all embodiments of the teachings of the invention fairly falling within the scope

22   of the appended claims either literally or under the doctrine of equivalents.